

# An Overview of Results Derived from Mobile-Satellite Propagation Experiments

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## ABSTRACT

During the period 1983-1988, a series of Land Mobile Satellite Service (LMSS) propagation experiments were performed in Southern United States (New Mexico to Alabama), Maryland, Colorado, and South-Eastern Australia. These experiments were implemented with transmitters on stratospheric balloons, remotely piloted aircraft, helicopters, and geostationary satellites (INMARSAT B2, Japanese ETS-V, and INMARSAT Pacific). The earlier experiments were performed at UHF (870 MHz) and the latter at both L Band (1.5 GHz) and UHF. The general objective of the above tests was to assess the impairment to propagation caused by trees and terrain for predominantly suburban and rural regions where cellular communication services are impractical. In this paper are presented an overview of the results derived from the above experiments.

## SINGLE TREE ATTENUATION-STATIC CASE

### Attenuation and attenuation coefficient

In Table 1 is given a summary of the single tree attenuation results at 870 MHz (circularly polarized transmissions) based on the measurements by Vogel and Goldhirsh [1] and Goldhirsh and Vogel [2] who employed transmitter platforms on remotely piloted aircraft and helicopters and a receiving system on a stationary vehicle.

### L-Band versus UHF attenuation scaling factor – static case

Ulaby et. al. [3] measured the attenuation properties at 50° elevation associated with propagation at 1.6 GHz through a canopy of red pine foliage in Michigan at both horizontal and vertical polarizations. Their measurements gives rise to an average attenuation coefficient of approximately 1.8 dB/m. Combining this result at L-band with the average value of 1.3 dB/m at UHF given in Table 1 suggests the following

$$F(f_L) \approx F(f_{UHF}) \sqrt{\frac{f_L}{f_{UHF}}} \quad (1)$$

where  $F(f_L)$  is expressed in dB or dB/m. Simultaneous attenuation measurements by the authors at 1.5 GHz and 870 MHz for the mobile vehicle case showed consistency with the expression (1).

### Tree attenuation versus season and path elevation angle

Figure 1 shows linear least square results of attenuation versus path elevation angle derived from measurements on the Callery Pear tree in October 1985 (full foliage) and March 1986 (bare branches)[2,4]. The best linear fit results in Figure 1 may be expressed as follows for  $\theta$  between 15° to 40°

### Full Foliage:

$$F_1(\theta) = -0.48\theta + 26.2 \quad (2)$$

### Bare Tree:

$$F_2(\theta) = -0.35\theta + 19.2 \quad (3)$$

where  $\theta$  is the elevation angle in degrees. The percentage rms deviations of the data points relative to the best fit expressions (2) and (3) were 15.3% and 11.1% (1.7 and 1.2 dB), respectively. We derive from (2) and (3) the average condition for  $f = 870$  MHz, and path elevation between  $15^\circ$  and  $35^\circ$

$$F(\text{full foliage}) \approx 1.35F(\text{bare tree}) \quad (4)$$

which states that for the static case, the maximum attenuation contribution from trees with leaves (at 870 MHz) is nominally 35% greater than the attenuation of trees without leaves. The rms deviation about the average for the coefficient in the expression (4) is approximately .01%.

## ATTENUATION DUE TO ROADSIDE TREES - DYNAMIC CASE

### Empirical fade distribution model

Cumulative fade distributions were systematically derived from helicopter-mobile [2,4] and satellite -mobile measurements [5] in the Central Maryland region. This formulation referred to here as the MSS "Empirical Fade Distribution Equation" (EFDE) for  $P = 1$  to 20% is given by

$$F_3(P, \theta) = -M(\theta) \ln P + B(\theta) \quad (5)$$

where  $F_3$  is the fade in dB,  $P$  is the percentage of distance (or time) the fade is exceeded, and  $\theta$  is the path elevation angle to the satellite. Least square fits of second and first order polynomials in elevation angle  $\theta$  (deg) generated for  $M$  and  $B$ , respectively, result in

$$M(\theta) = a + b\theta + c\theta^2 \quad (6)$$

$$B(\theta) = d\theta + e \quad (7)$$

where

$$\begin{cases} a = 3.44 & b = .0975 \\ c = -0.002 & d = -0.443 & e = 34.76 \end{cases} \quad (8)$$

In Figure 2 are given a family of cumulative distributions (percentage versus fade exceeded) for the indicated path elevation angles.

### L-Band versus UHF attenuation scaling factor—dynamic case

Simultaneous mobile fade measurements by the authors [2,4] at L-Band (1.5 GHz) and UHF (870 MHz) have demonstrated that the ratio of fades are approximately consistent with the square root of the ratio of frequencies formulation given by (1). The results demonstrated that for  $f_L = 1.5$  GHz and  $f_{UHF} = 870$  MHz

$$F(f_L) \approx 1.31F(f_{UHF}) \quad (9)$$

The multiplying coefficient 1.31 was shown to have an rms deviation of  $\pm 0.1$  over a fade exceedance range from 1% to 30%.

### Seasonal effects—dynamic case

Seasonal measurements were performed by the authors for the dynamic case in which the vehicle was traveling along a tree-lined highway in Central Maryland (Route 295) along which the propagation path was shadowed over approximately 75% of the road distance [2,4]. Cumulative fade distributions were derived for March 1986 during which the deciduous trees were totally without foliage. These were compared with similar distributions acquired in October 1985 and June 1987, during which the trees were approximately in 80% and full blossom stages, respectively. For the "dynamic case" at a frequency  $f = 870$  MHz and  $P = 1\%$  to 30%

$$F(\text{full foliage}) = 1.24F(\text{no foliage}) \quad (10)$$

### Fade reduction due to lane diversity

We examine the extent by which the fade reduces (or increases) by switching lanes for MSS configurations. For the case in which the satellite path and the tree line is to the right of the vehicle direction, the path length through the canopies of roadside trees is greater when the vehicle is in the right lane. A fade reduction should therefore be experienced by switching lanes from the right to the left side of the road. The authors measured this effect at UHF (870 MHz) and L Band (1.5 GHz) in Central MD [2,4,5]. A quantity defined as the "fade reduction, FR" is used to characterize the increase in signal power gained by switching lanes. This quantity is obtained by differencing equi-probability fade values from distributions pertaining to right and left side driving. The fade reduction at L-Band is plotted in Figure 3 for the indicated elevation angles as a function of the maximum fade as derived (for the example given) from right versus left lane driving.

At each of the elevation angles, the individual data points have been replaced by the "best fit third order polynomial" which may be expressed by

$$FR = A_0 + A_1F + A_2F^2 + A_3F^3 \quad (11)$$

where FR (in dB) represents the fade reduction obtained in switching lanes from the greater shadowing configuration to the lesser one. Also,  $A_0$ ,  $A_1$ ,  $A_2$ , and  $A_3$  are tabulated in Table 2 for L-band. The parameter F (in dB) represents the maximum fade level value. The "best fit polynomials" were observed to agree with FR as derived from the measured distributions to within 0.1 dB rms.

## PROPAGATION IMPAIRMENT-LINE OF SIGHT COMMUNICATIONS

### Multipath for a mountain environment

The results described here were obtained from MSS line of sight measurements in canyon passes in North-Central Colorado [6]. The transmitter was on a helicopter which, for each run, flew behind a receiving mobile van and maintained a relatively fixed distance and path depression angle relative to the receiving antenna. The radiating antennas on the helicopter transmitted simultaneous L-Band (1.5 GHz) and UHF (870 MHz) cw signals.

Figure 4 shows four cumulative fade distributions depicting "least square power curve fits" for the above described multipath scenario at a frequency of 870 MHz and 1.5 GHz and path elevation angle 30° or 45°. The resultant curves define the combined distribution corresponding to a driving distance of 87 km through canyon passes. Each of the best fit power curves agree with the measured cumulative distribution data points to within 0.1 dB rms. The distributions may be expressed for  $P = 1\%$  to 10% by

$$P = aF^{-b} \quad (12)$$

where  $a$  and  $b$  are tabulated in Table 3 at the two frequencies and elevation angles.

### Multipath Due to Roadside Trees

Similar type "line of sight measurements" as described above for mountainous terrain were also performed by the authors in Maryland along tree lined roads [4]. The resultant distribution was found to follow the exponential form for  $P = 1\%$  to 50%

$$P = u \exp(-vF) \quad (13)$$

where  $u$  and  $v$  are tabulated in Table 4 and the corresponding distributions are plotted in

Figure 5. Since negligible differences in the individual cumulative distributions existed for  $\theta = 30^\circ, 45^\circ$ , and  $60^\circ$ , they were combined in the determination of (13).

## OTHER PROPAGATION IMPAIRMENT EFFECTS

The authors have characterized a number of other propagation impairment effects for which limited space here does not allow their characterization [4,7,8]. These include distributions associated with "fade duration", "non-fade duration", "antenna space diversity", "cross polarization effects", and "high versus low antenna gain effects".

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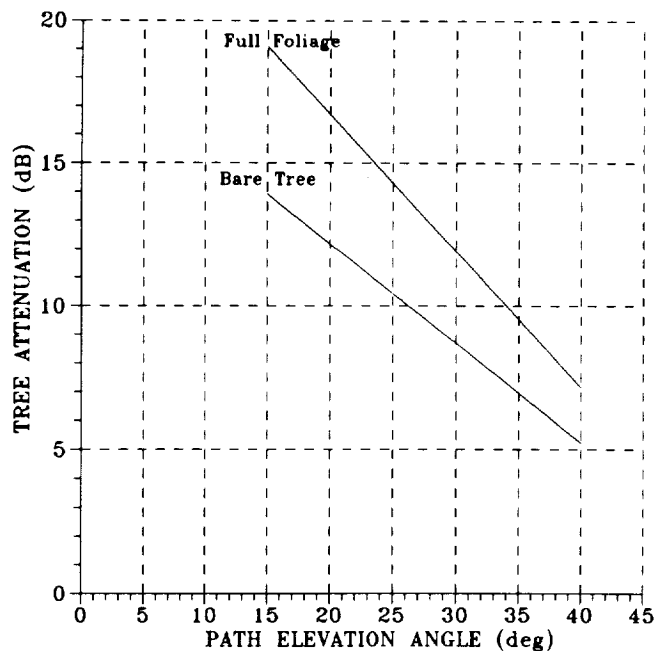


Figure 1: Least square linear fits of attenuation versus elevation angle for propagation through the canopy of a Callery Pear Tree at 870 MHz.

Table 1: Single Tree Attenuations at  $f = 870$  MHz

Tree Type	Attenuation (dB)		Attenuation Coef. dB/m	
	Largest	Average	Largest	Average
Burr Oak*	13.9	11.1	1.0	0.8
Callery Pear	18.4	10.6	1.7	1.0
Holly*	19.9	12.1	2.3	1.2
Norway Maple	10.8	10.0	3.5	3.2
Pin Oak	8.4	6.3	0.85	0.6
Pin Oak*	18.4	13.1	1.85	1.3
Pine Grove	17.2	15.4	1.3	1.1
Sassafras	16.1	9.8	3.2	1.9
Scotch Pine	7.7	6.6	0.9	0.7
White Pine*	12.1	10.6	1.5	1.2
Overall Average	14.3	10.6	1.8	1.3

Table 2: Coefficients of fade reduction formulation (11) for lane diversity at  $f = 1.5$  GHz.

El. Angle $\theta$ (deg)	$A_0$	$A_1$	$A_2$	$A_3$	dB Range
30	0.3931	0.2416	$-1.420 \times 10^{-2}$	$-3.389 \times 10^{-4}$	3-26
45	-1.073	0.8816	$-4.651 \times 10^{-2}$	$7.942 \times 10^{-4}$	3-17
60	-0.1962	0.2502	$5.244 \times 10^{-2}$	$-2.047 \times 10^{-3}$	3-16

Table 3: Coefficients  $a$  and  $b$  in best fit cumulative fade distribution formulation (12) for multipath in mountainous terrain.

Frequency (GHz)	El = 30°			El = 45°		
	$a$	$b$	dB Range	$a$	$b$	dB Range
0.870	34.52	1.855	2-7	31.64	2.464	2-4
1.5	33.19	1.710	2-8	39.95	2.321	2-5

Table 4: Coefficients  $u$  and  $v$  in formulation (13) describing best exponential fit cumulative fade distributions for multipath for tree-lined roads.

Frequency (GHz)	$u$	$v$	Fade Range (dB)
0.870	127.7	0.8573	1-4.5
1.5	125.6	1.116	1-6

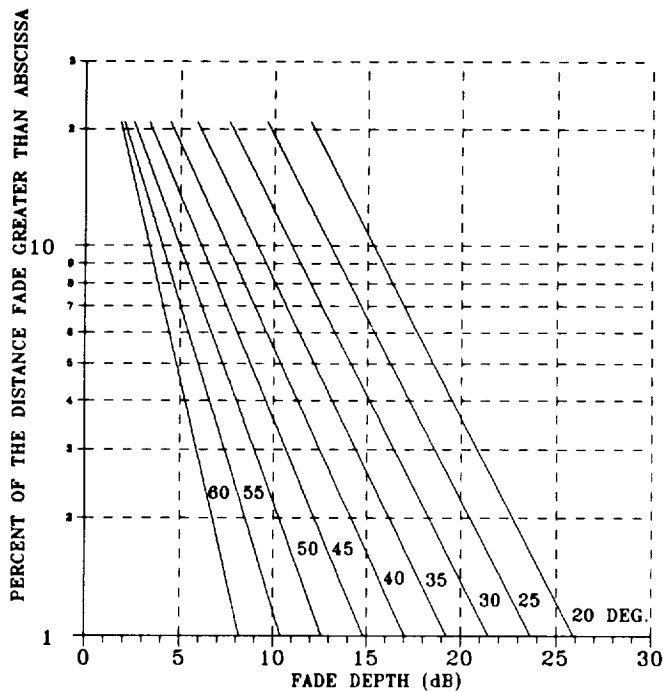


Figure 2: Cumulative fade distributions at 1.5 GHz for family of path elevation angles derived from the MSS Empirical Fade Distribution Equation (EFDE).

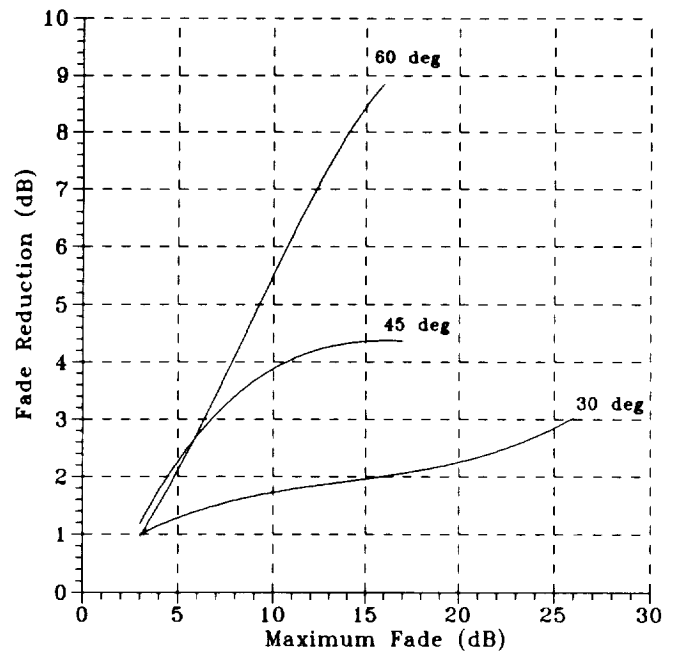


Figure 3: Best fit fade reduction at 1.5 GHz versus equi-probability attenuation at path elevation angles of 30°, 45°, and 60°.

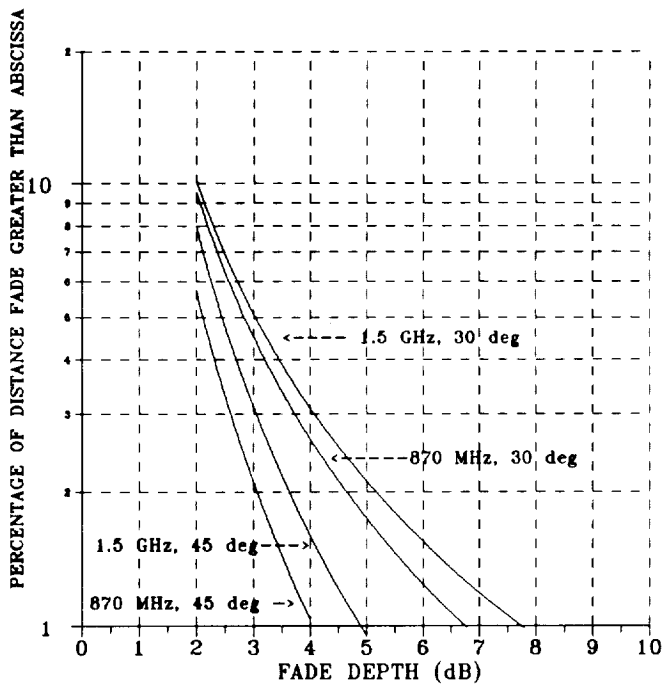


Figure 4: Best power curve fit cumulative fade distributions for line of sight configurations in mountainous terrain.

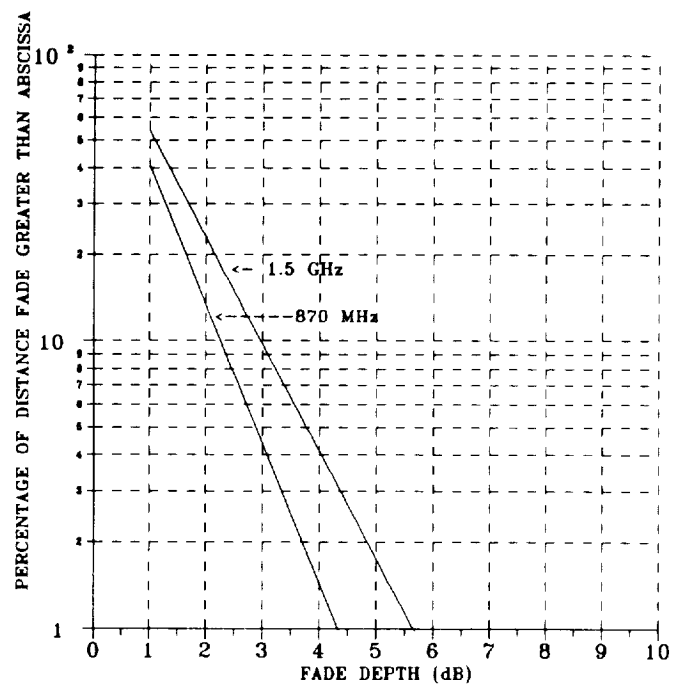


Figure 5: Best exponential fit cumulative fade distributions for line of sight configurations for tree-lined roads.